Scottish Universities Environmental Research Centre

Mobile Gamma Spectrometry Survey of the Scottish Enterprise Technology Park, East Kilbride, 17th-19th August 2009

A.J. Cresswell, D.C.W. Sanderson
Scottish Universities Environmental Research Centre

A. Weir, C. Mitchell
Dept. Of Physics and Astronomy, University of Glasgow

November 2010

East Kilbride Glasgow G75 OQF Telephone: 01355 223332 Fax: 01355 229898

Summary

Environmental radioactivity arises from natural geological sources, the redistribution of natural activity through industrial processes, the nuclear industry including routine and accidental discharges into the environment, and various medical or industrial uses of radioisotopes. Mobile gamma spectrometry provides a powerful means of measuring the distribution of radioactivity in the environment. Data collected by such methods provide measures of environmental quality, references for public health assurance, means to assess environmental change, and other uses. Airborne Gamma Spectrometry (AGS) has been developed at SUERC for environmental purposes since 1988, and provides a capability for very rapid and cost effective surveys of large areas, and provides for visualisation and classification of enhanced features of radioactivity within the context of natural variations. Ground based approaches, with equipment mounted on vehicles or backpacks, provide more detailed spatial resolution for smaller areas at significantly reduced area coverage rates.

A portable gamma spectrometry system has been developed at SUERC, consisting of a 3x3" NaI(Tl) detector with a digital spectrometer and GPS receiver using a netbook computer for data acquisition. This system can be carried as a backpack and used to conduct surveys of environmental radioactivity in urban areas, where people spend their time.

Detector backgrounds and stripping matrices have been measured. A survey of approximately 50,000 m^2 of the Scottish Enterprise Technology Park (SETP) has been conducted with two detector systems. The SETP is on the site of the National Engineering Laboratory (NEL) established in East Kilbride in 1948, and acquired by Scottish Enterprise in 1994. In recent years there has been an ongoing programme of renovation on the site, including demolition of old buildings and new construction along with landscaping operations.

This report presents the results of initial detector characterisation and the survey of part of the SETP site. Detector stripping matrices were determined from measurements made on the 18th August 2009, with background measurements on Loch Lomond collected on the 28th. The site survey was conducted between 17th and 19th August 2009, with over 4600 spectra with 10s integration time collected. Maps of the distribution of ^{137}Cs, ^{40}K, ^{214}Bi, ^{208}Tl and gamma dose rate were produced. The ^{137}Cs activity clearly shows areas undisturbed since 1986, with fallout from the Chernobyl accident still present on the grass. The footprint of the demolished research reactor at SUERC is evident as a negative feature in the ^{137}Cs map. The natural series activities and gamma dose rate show the range of materials used for building and road construction, including one small area of Technologically Enhanced Naturally Occurring Radioactive Material (TENORM), and the local geology and soils. This demonstrates the capability of the SUERC portable gamma spectrometry system to collect high quality data of an area with a complex history, land use and range of buildings. Further application of the technique to other urban areas, and the rest of the SETP site, would allow similar assessments of the radiation environments of a range of different locations.

Contents

List of Figures

List of Tables

1. INTRODUCTION

Radiation in the environment arises from a range of natural and anthropogenic sources. Primordial radionuclides with very long half lives (principally ^{238}U, ^{232}Th and ^{40}K) with their decay products exist in differing concentrations in rocks and soils. Industrial processes, for example ore processing, can enhance the concentrations of some naturally occurring radioactive isotopes, producing Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM). Anthropogenic radionuclides are produced by nuclear processes, such as fission or neutron activation, and may be present in the environment as a result of discharges from nuclear sites or fallout from nuclear accidents and weapons testing. Radioactive sources are used for a variety of purposes, both in fixed locations and mobile equipment, and have in the past been lost or stolen. Mobile gamma spectrometry provides powerful methods of measuring the distribution of radioactivity in the environment; airborne platforms allow the rapid survey of large areas, and ground based platforms more detailed surveys of smaller areas.

Urban environments present particularly complex potential radiation fields. In addition to underlying geology and soils presenting natural radiation fields, urban areas contain a range of building, and other construction, material imported from other locations which may have different concentrations of natural activity and displace local soils. Sites with industrial histories may also contain materials which have been altered by industrial processes, including TENORM. Some industrial slag material is particularly hard and dense and has been used in some locations as hard-core for construction projects. And, finally, the topographic relief of the built environment presents ever changing geometries to mobile detectors.

The Scottish Enterprise Technology Park (SETP) is an example of an urban environment with a range of different buildings and a history of construction, demolition and reconstruction. The Scottish Universities Environmental Research Centre (SUERC) is located on the site, and thus it is a convenient location to demonstrate the capabilities of mobile gamma spectrometry systems.

The SETP is on the site of the National Engineering Laboratory (NEL) established in East Kilbride in 1948, and acquired by Scottish Enterprise in 1994. The NEL was a government funded laboratory focussing on mechanical engineering research, and holds the national standard for flow measurement. Reorganisation resulted in the NEL becoming part of the German owned TUV group in 1995. The laboratories of the Scottish Universities Environmental Research Centre (SUERC) are also on the SETP site. This includes the main building, which was opened in 1963 as a research reactor centre, a radiocarbon laboratory and Accelerator Mass Spectrometry (AMS) laboratory. The research reactor on the site was shut in 1995, the reactor hall and all associated equipment have now been removed from the site and the buildings are no longer a licensed nuclear site. The University of Glasgow Kelvin Laboratory, which housed a linear electron accelerator, was also on the site. In recent years there has been an ongoing programme of renovation on the site, including demolition of old buildings and new construction along with landscaping operations. New buildings for South Lanarkshire College have recently been opened at the south east of the site. Other tenants on the site include the Building Research Establishment Scotland (BRE), a leading centre of expertise in construction to an international customer base. The Energy Technology Centre provides a resource for the development and testing of renewable energy systems.

A lightweight, portable gamma spectrometry system has been developed at SUERC. This uses a 3x3” NaI(Tl) detector with digital spectrometer, GPS receiver and netbook computer. Used as a backpack system, this allows high resolution measurements of the distribution of environmental radioactivity in small survey areas, and is ideally suited to such studies in the urban spaces within which people spend their time. A student project with the Department of Physics and Astronomy at the University of Glasgow (Mitchell & Weir 2010) has characterised the response of the detectors, including determination of stripping matrices and background, and utilised the system in a demonstration of capability by mapping the natural and anthropogenic radioactive environment of part of the SETP, including the SUERC site.

2. RESULTS

2.1 Background Measurements

The detector system includes a low level signal from materials within the detector, and contributions from cosmic rays. The contribution of these background signals in each spectral window can be determined by recording spectra in an environment with negligible external radiation sources. The detector systems were taken to Loch Lomond on August 28th 2009, and measurements taken from a plastic boat operated by the Scottish Centre for Ecology and the Natural Environment, at a point over deep water more than 1km from the shores of the Loch. The mean and standard error for the count rates in the spectral windows used for analysis of the backpack measurements are given in the Appendix, Table A.1. The gamma dose background had been measured for the Torness Survey (Sanderson *et.al.* 1994) as 2.2cps, which is significantly lower than that measured here. The 1994 measurement used one of the detectors used here, but with a simple voltage divider on the photomultiplier rather than the Ortec digiBASE™ used here. It is possible that the more complex modern device introduces additional background counts, and that the detector performance has degraded in the intervening 15 years.

2.2 Stripping Ratio Measurements

Spectral windows used for data analysis of mobile gamma spectrometry data include some contributions from other isotopes, as a result of both additional gamma ray decay lines associated with natural series decay chains and scattered radiation. These interferences are removed to produce pure nuclide count rates by the use of a stripping matrix. This matrix is determined from pure nuclide spectra. Measurements were conducted on a set of calibration pads at SUERC on August 18th 2009.

There are four concrete calibration pads at SUERC. These are constructed of concrete manufactured with low activity materials; one is untreated concrete (the “background pad”) and the other three are doped with potassium salt, uranium and thorium ores. In addition, a set of plywood sheets coated in paint doped in ^{137}Cs and point sources are available for anthropogenic spectra. Spectra were recorded for each system for 15-20 minutes on each pad and with the ^{137}Cs sheets. The mean count rates for each window on the background pad were subtracted from each of the other set of mean count rates, giving net count rates for pure spectral sources. The ratios of these net count rates are used to determine stripping matrices, as given in the Appendix, Tables A.2 and A.3.

2.3 Detector Sensitivity Estimate

A calibration is applied to convert stripped count rates to activity concentrations (per unit mass for the natural series, per unit area for ^{137}Cs). The values used are taken from the PhD theses of A.N. Tyler (1994) and J.D. Allyson (1994) derived from field measurements and photon-fluence calculations. Gamma dose rate is determined from the count rate for all events with energy greater than a nominal 450keV, with a conversion factor determined from the work of J.D. Allyson and A.N. Tyler, and found to compare well with radiation physics instruments used at Torness (Sanderson *et.al.* 1994). These conversion factors are given in the Appendix, Table A.4.

2.4 Scottish Enterprise Technology Park Survey

An area of approximately 50,000 m^2 of the Scottish Enterprise Technology Park in East Kilbride was surveyed between the 17th and 19th August 2009. Approximately 4600 spectra were recorded with an integration time of 10s. Figure 2.1 shows the location of the measurements.

The data were processed to produce maps of the distribution of ^{137}Cs, ^{40}K, ^{214}Bi (^{238}U decay series), ^{208}Tl (^{232}Th decay series) and gamma dose rate. These maps are shown in Figures 2.2-2.6.

^{137}Cs is a fission product, produced in nuclear reactors and bombs. The ^{137}Cs in the environment of the Scottish Enterprise Technology Park derives mostly from fallout following the 1986 Chernobyl accident. As can be seen in Figure 2.2, the activity concentration in this area is generally very low. There are some slightly higher levels amongst trees around the edge of the site, and also on the grass areas in front of and behind the SUERC main building and some other locations. The activity is observed on soft surfaces that have remained undisturbed since 1986. Where ground has been re-worked, ^{137}Cs activity concentrations are below detection. Behind the main SUERC building, for example, there is a negative feature showing the area where the reactor block had been prior to its demolition.

The ^{40}K, ^{214}Bi and ^{208}Tl distributions reflect underlying geology and soils, and building and road materials. In all three maps in Figures 2.3-2.5, the concrete calibration pads just south of the main SUERC building are evident. To the north of the surveyed area, a side road between Prism House and the GWR site shows elevated uranium (^{214}Bi, Figure 2.4) and thorium (^{208}Tl, Figure 2.5) series activity without any associated increased ^{40}K activity (Figure 2.3). This is not a ratio of activities observed in naturally occurring materials. Investigation of the road revealed the presence of waste industrial material along the road side, evidently used as hard core for construction.

The gamma dose rate (Figure 2.6) follows the natural series maps.

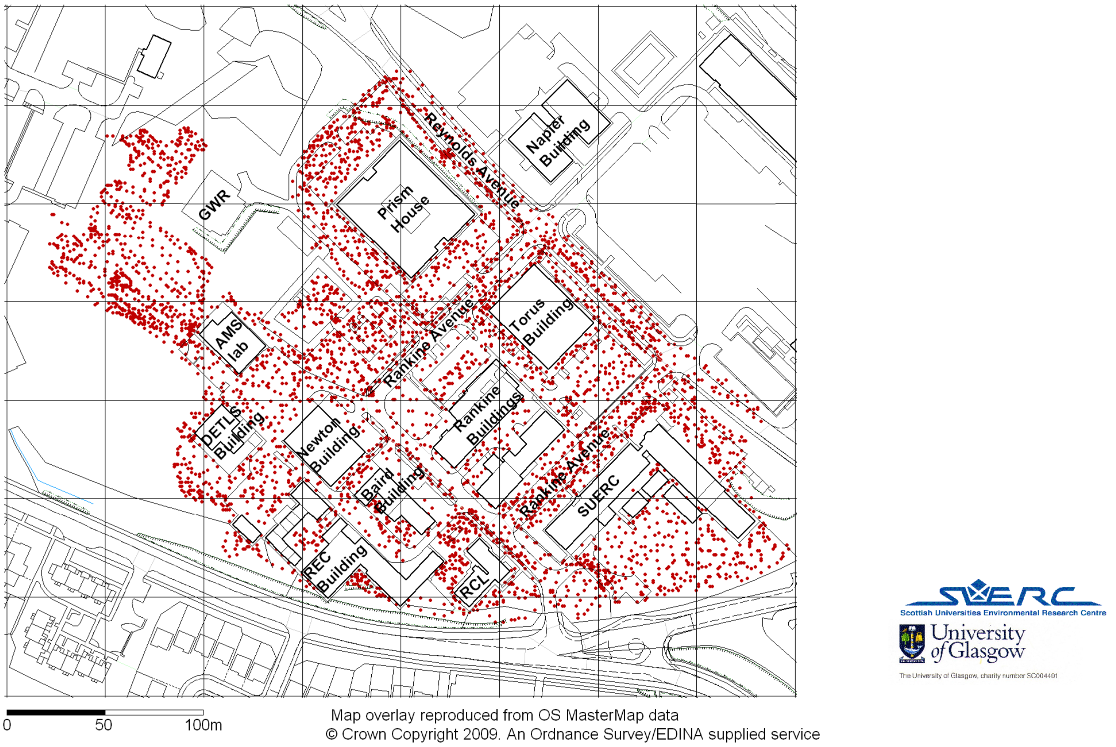

Figure 2.1: Location of backpack measurements on the Scottish Enterprise Technology Park.

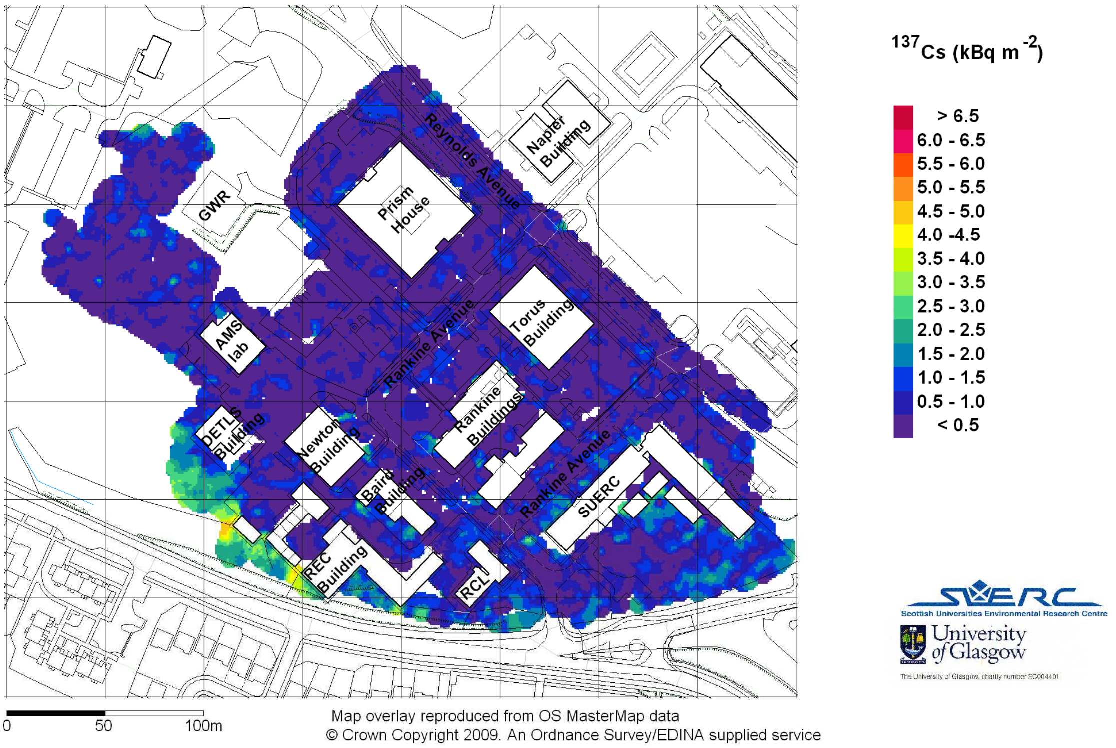

Figure 2.2: ^{137}Cs activity per unit area.

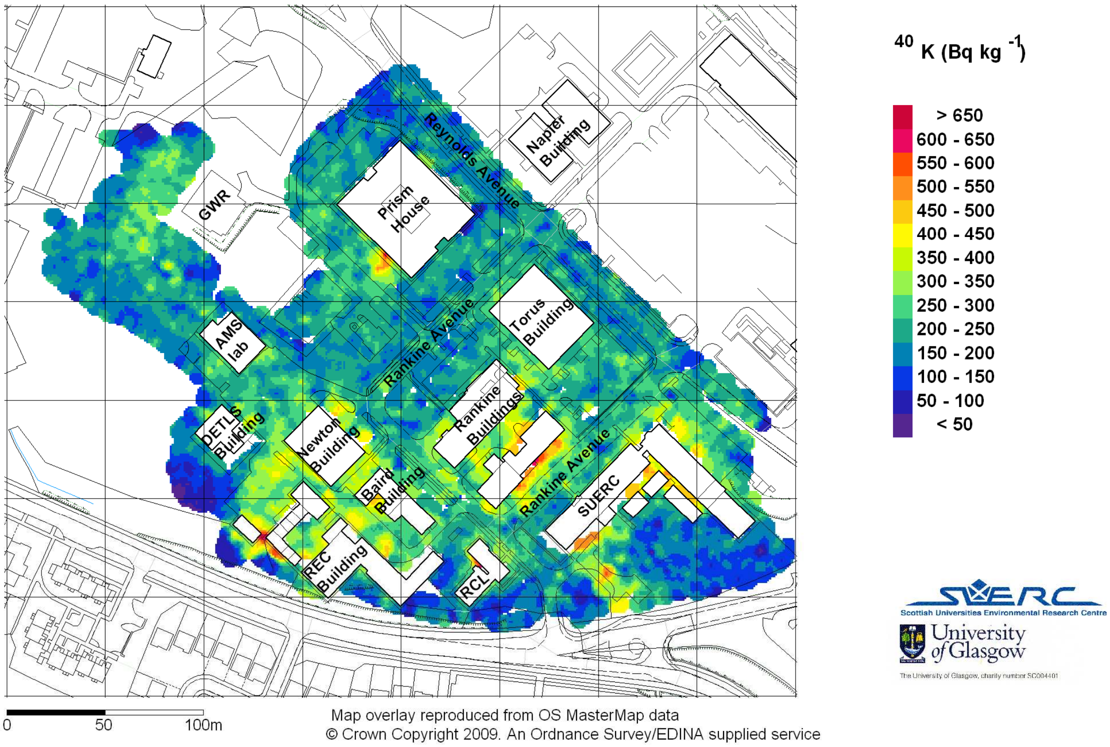

Figure 2.3: ^{40}K activity per unit mass

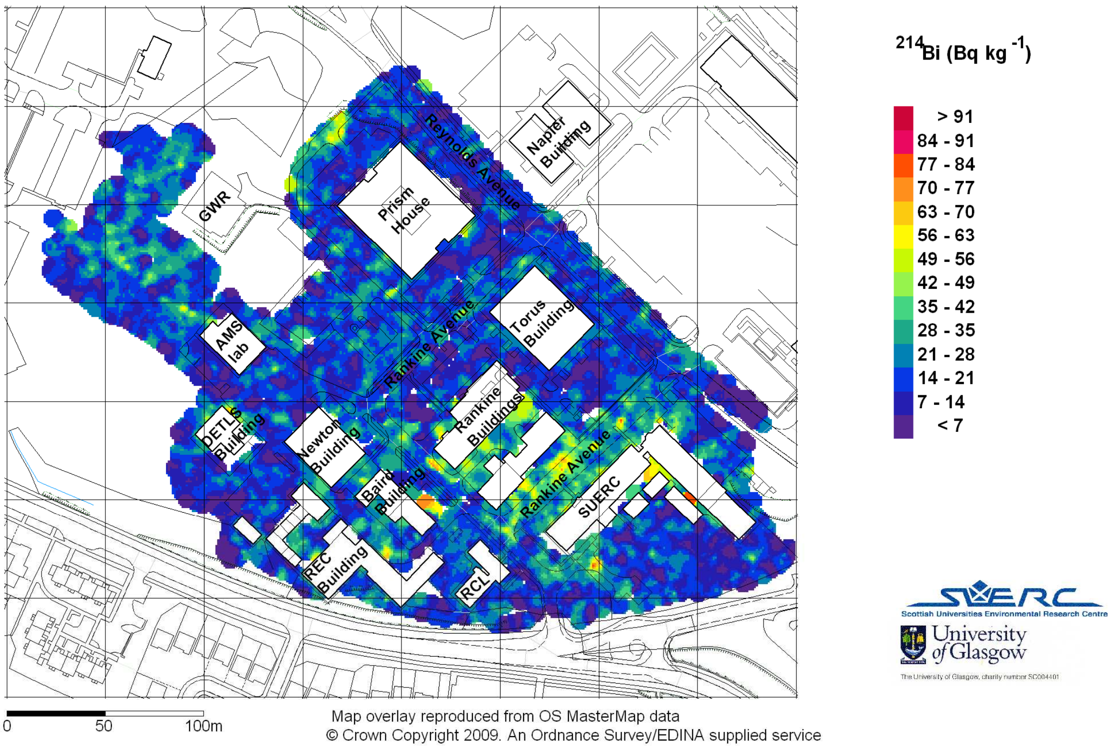

Figure 2.4: ^{214}Bi activity per unit mass

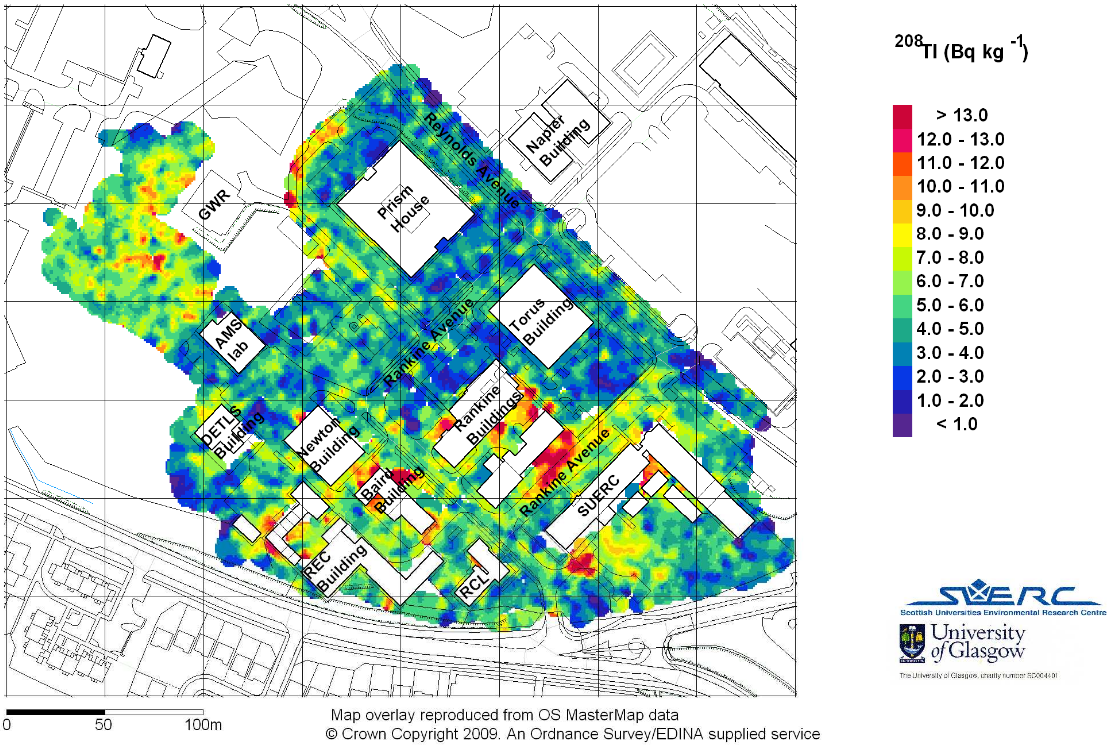

Figure 2.5: ^{208}Tl activity per unit mass

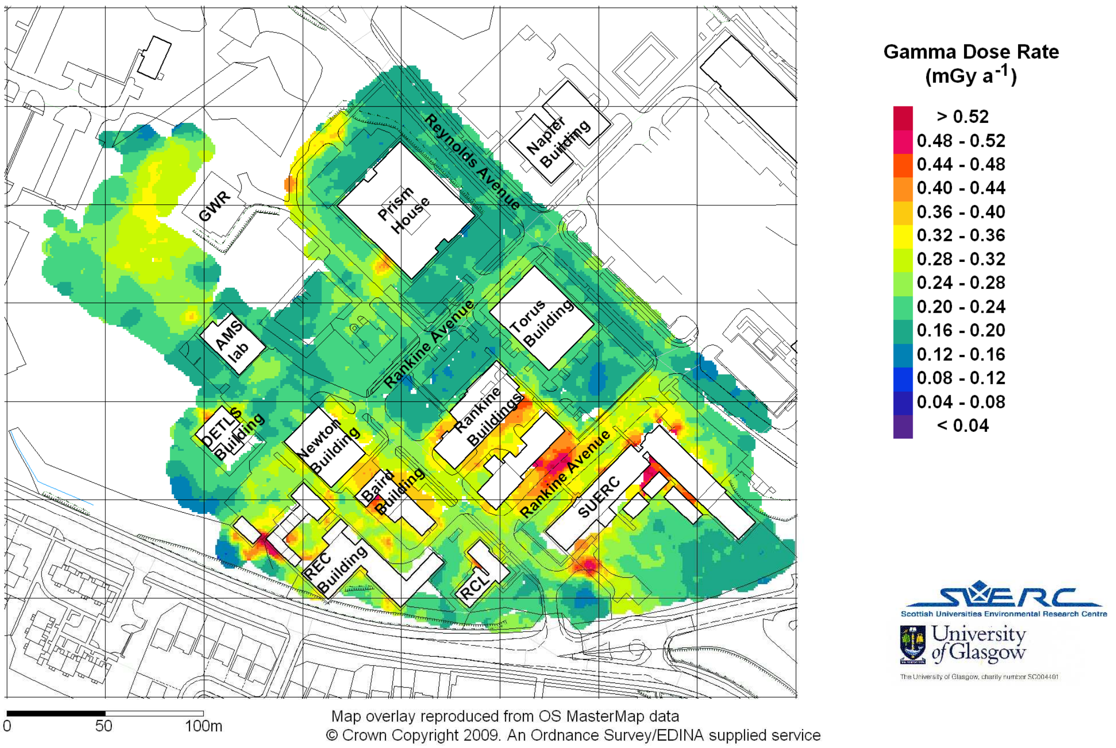

Figure 2.6: Gamma dose rate

3. DISCUSSION AND CONCLUSIONS

Detector backgrounds and stripping matrices have been determined for two 3x3" NaI(Tl) detectors. These detectors are used with digital spectrometers, GPS receivers and netbook computers as lightweight portable gamma spectrometry systems. These have been used to map the radiation environment of the Scottish Enterprise Technology Park.

The survey, between the 17th-19th August 2009, collected over 4600 spectra with a 10s integration time, covering approximately 50,000 m^2 of the Technology Park, including the areas surrounding the main SUERC building, the Radiocarbon Laboratory and the Accelerator Mass Spectrometry laboratory. The ^{137}Cs distribution reflects disturbance of the environment since the 1986 Chernobyl accident, with undisturbed soil retaining fallout from that event. The footprint of the demolished reactor block at SUERC is evident as a negative feature in the ^{137}Cs map. The ^{40}K, ^{214}Bi and ^{208}Tl distributions, and the gamma dose rate, reflect the geology and building and road surface materials. The doped concrete calibration pads at SUERC are evident. An area of Technologically Enhanced Naturally Occurring Radioactive Material (TENORM) was located along an old side road, where industrial waste material had been used as hard core.

Acknowledgements

The support of the Scottish Centre for Ecology and the Natural Environment (SCENE) in allowing us to use one of their boats for background measurements is acknowledged, in particular the help of Davey Fettes in arranging for the boat to be available and Stuart Wilson for driving the boat.

References

Allyson, J.D. (1994). *Environmental Gamma Ray Spectrometry: Simulation of Absolute Calibration of in-situ and Airborne Spectrometry for Natural and Anthropogenic Sources.* PhD Thesis, The University of Glasgow.

Mitchell, C., Weir, A. (2010). *A Study of Environmental Radioactivity*. Undergraduate Project Report for the Department of Physics, University of Glasgow.

Sanderson, D.C.W., Allyson, J.D., Ni Riain, S., Gordon, G., Murphy, S., Fisk, S. (1994). *An Aerial Gamma Ray Survey of Torness Nuclear Power Station on 27th-30th March 1994.* SURRC Report for Scottish Nuclear Limited.

Tyler, A.N. (1994). *Environmental Influences on Gamma Ray Spectrometry.* PhD Thesis, The University of Glasgow.

Appendix: Data Processing Parameters Used

Window	Radionuclide	Channel range	Energy range (keV)	Background (cps)	
				System 1	System 2
1	^{137}Cs (661keV)	98 – 122	538 – 694	1.03 ± 0.02	1.03 ± 0.02
2	^{60}Co (1173keV)	184 – 208	1095 – 1251	0.32 ± 0.02	0.36 ± 0.01
3	^{40}K (1461keV)	228 – 254	1380 – 1549	0.39 ± 0.03	0.48 ± 0.01
4	^{214}Bi (1764keV)	272 – 303	1665 – 1866	0.14 ± 0.03	0.17 ± 0.01
5	^{208}Tl (2614keV)	403 – 440	2513 – 2754	0.103 ± 0.003	0.11 ± 0.01
6	Gamma dose	75 – 500	390 – 3140	5.00 ± 0.05	5.39 ± 0.05

Table A.1: Spectral windows and backgrounds.

	1 (^{137}Cs)	2 (^{60}Co)	3 (^{40}K)	4 (^{214}Bi)	5 (^{208}Tl)
^{137}Cs sheet	1	0	0	0.002	0
^{60}Co source	0	1	0	0	0
K pad	0.669	0.469	1	0	0
U pad	5.303	1.623	0.815	1	0.025
Th pad	4.946	0.755	0.592	0.642	1

Table A.2: Stripping matrix for system 1

	1 (^{137}Cs)	2 (^{60}Co)	3 (^{40}K)	4 (^{214}Bi)	5 (^{208}Tl)
^{137}Cs sheet	1	0	0	0.001	0
^{60}Co source	0	1	0	0	0
K pad	0.666	0.455	1	0	0
U pad	5.254	1.587	0.810	1	0.021
Th pad	4.887	0.729	0.642	0.652	1

Table A.3: Stripping matrix for system 2

Window	Calibration constant	Calibrated unit
1. ^{137}Cs	0.5	kBq m^{-2}
2. ^{60}Co	1	cps
3. ^{40}K	89	Bq kg^{-1}
4. ^{214}Bi	39	Bq kg^{-1}
5. ^{208}Tl	8.7	Bq kg^{-1}
6. Gamma dose rate	0.0061	mGy a^{-1}

Table A.4: Calibration coefficients